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Energy Efficiency Enhancement in Cotton Pneumatic Transport Systems Using Parallel Pipelines

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Abstract

The efficiency of pneumatic conveying systems plays a decisive role in the energy performance of cotton-processing plants, where airflow is the dominant electrical power consumption. Despite widespread industrial use, conventional single-duct systems still suffer from high pressure losses and energy inefficiency due to excessive air velocity and wall friction. Previous studies primarily focused on granular or powdered materials, while the specific aerodynamic behaviour of low-density fibrous cotton remains insufficiently investigated. This knowledge gap limits the optimisation of energy-saving designs for cotton pneumatic transport.

This research develops a mathematical and experimental model for a resource-efficient pneumatic conveying system employing parallel pipelines to enhance energy efficiency and transport stability. The model integrates Bernoulli's principle, the Darcy–Weisbach equation, and empirical correlations for friction and particle-air interaction. Comparative simulations and experiments were performed for single- and dual-pipeline configurations operating at air velocities of 15-20 m/s.

The results show that the parallel configuration reduces pressure drop by 23-26% and total power consumption by 20-25% compared to the conventional 355 mm single-duct system, while maintaining stable fibre transport and minimising clogging. The findings validate the theoretical framework and provide practical guidelines for retrofitting existing cotton pneumatic systems to achieve substantial energy savings.

This study fills a key research gap by demonstrating the aerodynamic advantages of parallel airflow distribution for fibrous materials. It contributes to sustainable industrial modernisation by offering a scalable, energy-efficient pneumatic transport design suitable for cotton-processing facilities worldwide.

Keywords: Cotton pneumatic transport; energy efficiency; parallel pipelines; airflow distribution; pressure loss; Bernoulli equation; resource-saving system.

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1 Introduction

Cotton production and processing remain integral to Uzbekistan's economic and industrial framework, a country where the cotton industry contributes significantly to GDP and employment. The transportation of raw cotton within processing plants has traditionally relied on pneumatic systems that use pressurised airflow through pipelines to move cotton fibres from one stage of processing to another. This method, while efficient in terms of speed and integration, is notoriously energy-intensive and prone to fibre damage, particularly under turbulent, high-speed conditions [7].

In Uzbekistan and other cotton-producing countries, where large-scale cotton processing facilities operate continuously, reducing energy use in pneumatic systems is an essential part of sustainable modernisation and cost optimisation. The need for resource-efficient pneumatic transport systems has therefore become a critical area of research in both academia and industry.

Traditional single-pipeline systems typically use ducts with diameters of 315-355 mm and operate at air velocities of 18-22 m/s to maintain stable fibre flow. Field data collected from regional cotton-processing facilities, as well as experimental studies by Sarimsakov [6, 14, 15], confirm these figures and further highlight inefficiencies related to airflow distribution and friction-induced losses.

Globally, researchers have long focused on optimising pneumatic systems for the transport of particulate material. In agricultural contexts, studies by Zhao [3], Kim [4], and Patel [5] underscore the potential for design innovations — such as curved ducts, adjustable fan speeds, and multi-duct layouts — to reduce energy requirements. However, limited attention has been paid to how these innovations could be adapted to the specific material properties of raw cotton, which is lightweight, compressible, and prone to damage under excessive mechanical stress.

A gap remains in the literature on the implementation of parallel ducting systems for cotton-specific pneumatic conveying. While parallel configurations have been proposed in mining, food processing, and chemical transport systems, their application to cotton handling requires further exploration.

The parallel-pipeline concept divides the airflow into two or more smaller ducts operating under synchronised pressure and velocity conditions. This allows reduced friction losses per duct, a more uniform distribution of fibre flow, and minimised turbulence at junction points. [Revised:] As a result, the total energy consumption can be reduced while maintaining or even improving the stability of cotton transport.

Although parallel pneumatic systems have been studied in industries such as cement, food, and chemical processing, their application in cotton ginning plants remains underexplored. The unique aerodynamic characteristics of cotton fibres—such as low density, irregular shape, and high surface area—demand specialised modelling and optimisation techniques distinct from those used for granular or powder materials.

This study aims to develop a mathematical and experimental model for a resource-efficient pneumatic conveying system designed with parallel ducts in a cotton transport setup. The research focuses on identifying the optimal diameters of the parallel ducts to minimise energy consumption without compromising the transport stability or the quality of cotton fibres. [Revised:] The model integrates fundamental fluid dynamics equations, including Bernoulli's principle, friction loss models, and empirical correlations derived from previous studies in pneumatic transport.